Recent Advances in Mercuric Iodide Detector Fabrication and Instrument Development*

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ABSTRACT

Mercuric Iodide is a preferred candidate material for truly room-temperature radiation detectors because of its large electronic bandgap (2.1 eV) and the high atomic number of its constituent elements, which results in a high photopeak efficiency. The spectroscopic performance of the detectors is determined by the electronic transport properties of the material which depends on the purity and the structural homogeneity of the single crystals from which the detectors are fabricated. Recent advances in purification and crystal growth have made it possible to fabricate routinely large,stable gamma ray and X-ray detectors and counters.

The gamma ray detectors (25mm x 25mm x 3mm) with a spectral resolution better than 4% at Cs^{137} are combined with a preamplifier and voltage filter in a stand-alone module which minimizes microphonic noise. This module can be incorporated in a portable spectrometer instrument with a total weight of less than 4 kg (batteries included). The counter detectors (25 mm x 25 mm x 5mm) are incorporated in a pocket-size radiation intensity counter with high sensitivity.

A short description will be given of the methods used to synthesize and purify material, to grow substantial single crystals up to 150 cubic centimeter in volume and to fabricate the detectors. The design and operation of the instruments will be discussed in more detail and performance characteristics will be presented. The operation of the instruments will be demonstrated if conditions permit.

Keywords: Mercuric Iodide, Radiation Detectors, Radiation Counters, Radiation Spectrometry Instruments

INTRODUCTION

For many years statements have been made that mercuric iodide was a very promising material for nuclear radiation detectors operating at room temperature. These statements were partly based on theoretical considerations of measured material properties and partly on detector results presented at open meetings and conferences. It was however very difficult for third parties to obtain samples for independent confirmation of the published results and no instruments were developed and distributed for general use.

Constellation Technology Corporation was in the fortunate position to assemble the technology of the different laboratories where the processes necessary to fabricate high quality mercuric iodide detectors had been practiced. With this background and by implementation of rigorous quality control and several process improvements it became possible to fabricate on a routine basis a variety of detectors with performance characteristics, which are suitable for instrument components.

In addition a complement of low-power, low-noise electronics has been developed which made possible the development of hand-held instruments which comply with customer requirements. The specific capabilities and mode of operation of two of these instruments will be demonstrated.

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DETECTOR FABRICATION

A general description of the processes which lead to the fabrication of mercuric iodide detectors has been given by H.A.Lamonds [1], but many of the details have been modified in order to maximize the electronic transport properties of the single crystalline material used to fabricate detectors. The mercuric iodide material is synthesized and purified in house so that the purity and the stoichiometry of the powder used in the crystal growth can be carefully controlled. The parameters of the crystal growth procedure itself have been subject to variations with the ultimate effect that the structural homogeneity of the resulting single crystalline material has increased.

The procedures to fabricate detectors that operate as spectrometers have likewise been optimized for routine production geared towards the goal of maximum attainable active volume at spectral resolutions of 3 to 4 percent. It is evident that better resolutions can be obtained with smaller volume detectors but this would reduce the efficiency accordingly and thereby increase the measurement times. The finished detectors are mounted on a small electronic board for easy handling and to accommodate the electronic system of the test boxes.

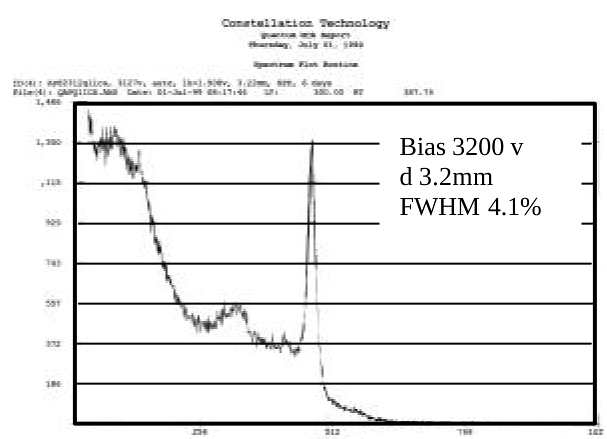
After preliminary testing the detectors are potted with a light-tight component and tested again for performance. At this stage they are ready to be used as a component for combination with a signal processing system or they can be mated with a conformal board which contains front end electronics.

Figures 1,2,3 and 4 show a finished detector, a detector after potting, a conformal preamplifier and voltage filter board and a spectrum obtained with one of these detectors.

Figure 1 – Finished Detector

Figure 2 – Potted Detector

Figure 3 – Preamplifier and voltage filter board



The size of the counter detectors is at this point determined by the sensitivity required and the dimensions of the enclosure of the detecting system which should be at most pocket-size and preferably pager size. The counters are tested at increasing biases till the detector saturates, which means that the maximum number of counts is being registered regardless of bias. The operating bias used is the lowest saturation bias, usually 900 to 1000 Volts.

RADIATION INTENSITY COUNTER

Instruments based on semiconductor detectors represent an attractive alternative for small size radiation detector systems operating at ambient temperatures. Because of its high efficiency, low leakage currents, stable gain and ruggedness, large volume mercuric iodide detectors are particularly suited for use in portable instrumentation.

A small gamma ray intensity counter with high sensitivity has been designed by Constellation Technology Corporation[2]. The dimensions of the instrument are 6.5 cm x 12.0 cm 2.7 cm and weighs 210 grams, including batteries (see fig. 5). The active volume of the detector is larger than 3 cm^3. The instrument can be used to monitor ambient radiation levels, to support search activities and to assist in customs inspections. The unit has a sensitivity of < 20 microRad/hour at 662 keV and uses approximately 2 mW provided by alkaline or lithium batteries. A liquid crystal bargraph provides a visual display of the count rate with increasing intensity levels from 20 to 2000 counts per second.

The front surface of the instrument has three control buttons to turn the instrument on or off, to set the alarm thresholds and to mute or set the alarm modes. The four alarm modes are audio alarm, vibratory alarm, simultaneous audio and vibratory and alarms off. When the instrument is activated it goes through a self-check mode to ascertain that all functions are operative.

Figure 5 - Radiation Intensity Counter

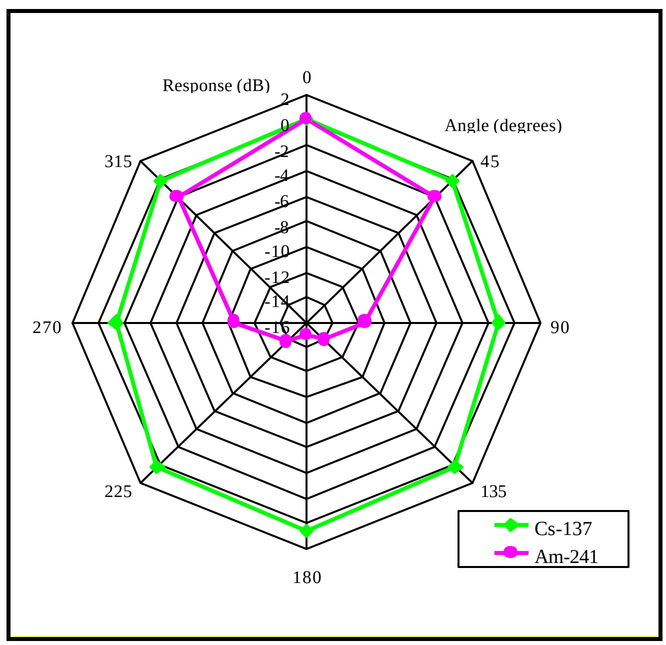


Figure 6 – Positional Response Plot

Extensive testing of each unit is performed before it is qualified, including the drop test per ANSI N13.27-1981, which requires performing three drop tests from a height of 5 feet on a hard surface before the instrument is turned on.

Orientational variations of the sensitivity whereby the instrument is rotated around one of its axes in front of a fixed source revealed that the front face of the instrument is more sensitive to radiation than the sides and the back, especially for energies less than 200 keV. Probable reasons for this are a reduced detector aperture presented to the source, but especially the attenuation of the radiation intensity caused by internal parts of the instrument. This effect may be an advantage when the unit is used to locate a source.

HAND – HELD SPECTROMETER

A modular system has been designed for the acquisition, display and analysis of gamma ray spectra. The complete package has dimensions of 19 cm x 23 cm x 6 cm and has a total weight of approximately 1800 grams (4 lbs), including the detector module and batteries (Figure 7). The lower part of the system houses the power supply, a storage capability of 32, 4000 channel spectra, a surface mount MCA with shaping times from 0.5 microseconds to 22 microseconds and a graphical LCD for spectral display. The collected data can be downloaded via a parallel port to enable the acquisition of more data and to perform analysis for isotope identification. Plans are to incorporate analysis software into the main module so that instant critical isotope information will be available to the operator in the field. The front panel also includes control buttons to activate the different operational modes of the system.

The detector module houses the detector and the front-end electronics. It can accommodate different types of solid state detectors fabricated from HgI_2, CdTe and CdZnTe and scintillator detectors with photomultiplier tubes or HgI_2 photodetectors. Figure 8 shows the inside of a detector module with a mercuric iodide spectrometer, preamplifier and voltage filter combined in one solid package. This module can remain attached to the main module during operation or it can be detached and remain connected through a cable connection.

Figure 7

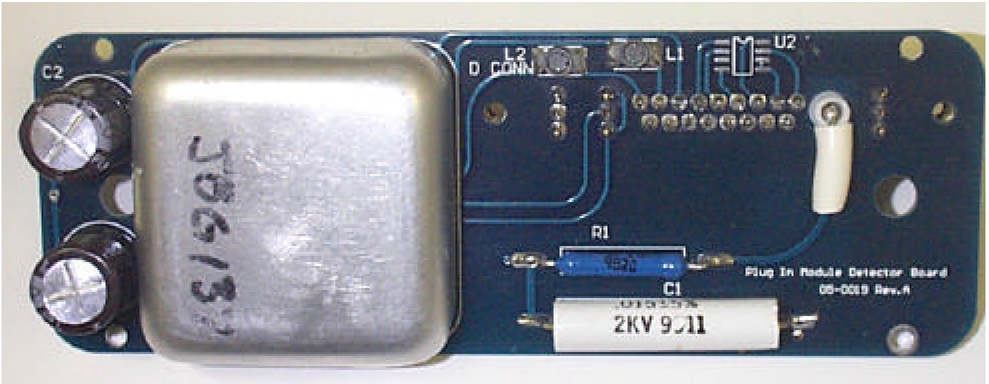


Figure 8

The unit is presently in the prototype stage and has been operating with a mercuric iodide detector for more than 8 hours on a set of 3 C-size alkaline cells. The spectral resolution is better than 3% at Cs^{137} as a result of advanced electronic systems used to optimize both the resolution and the efficiency and the use of long shaping times which is possible with a mercuric iodide detector because of its low leakage current.

SUMMARY

Mercuric iodide processing has been developed to the point where large volume counter and spectrometer detectors can be fabricated on a routine basis. Two light-weight, rugged, handheld instruments have been designed which incorporate these detectors. The guiding principles for this work were sensitivity and spectroscopic resolution requirements by primarily government or government related agencies.

The detectors are packaged as a component whose connections fit standard electronic board dimensions to facilitate general use. The instruments are available for both government and public applications.

(1) Lamonds, H.A., “Review of Mercuric Iodide Development Program in Santa Barbara”, Nucl. Inst. Meth. 213, 5 – 12 (1983)
(2) Pauly, S., et. al., “A Portable Radiation Intensity Counter for Nonproliferation Applications”, Proceedings INMM 1998